THE STRUGGLE FOR PAPER UNIFORMITY

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ABSTRACT

The performance of paper is greatly affected by its uniformity. The quest for uniformity on a paper machine is traced over a ten-year period. Non-uniformity first manifested itself in paperback books that would not lay flat. Later it caused problems with the register when paper was converted into forms. The phenomenon was related to moisture variations going into the dryer, resulting in non-uniform dried-in stresses.

Wet end surveys were performed to determine the source of the non-uniformity and the problems were tackled, as they became apparent. Some of the highlights are presented in this paper. These include changing impellers on pumps, adding foils in the screens, performing modal and finite element analysis to design a new headbox support system, adding damping to reduce vibration on the headbox, and adding a top former. Ensuring that no new problems came from rotating elements on or off the machine has also been an integral part of the process. Some observations of machine design are included.

To pro-actively prevent quality problems introduced by basis weight non-uniformity, the mill implemented a system to measure the basis weight non-uniformity on-line. The measurement is used as part of its acceptance criteria for certain grades of paper.

INTRODUCTION

The problems on this machine started with the paper in paperback books cockling, making the books much thicker. At times, they were twice as thick as they should have been. Subsequently, when the forms product line was started, there were problems with register variations in the converting process. These problems were manifested when perforations did not line up with the printed indications of where the perforations should be. Additionally, the tractor holes would not be in a straight line when the forms were stacked.

The headbox was installed on the paper machine in the early eighties. In the mid-eighties, the forming section was rebuilt, which required the headbox to be raised. Putting an extra spacer under the headbox did this. It was after this rebuild that basis weight variation problems became apparent. Most of the work reported here was done during this period. Later, the machine was converted to a top former.

The machine has a two nip straight through press and a conventional dryer section with the first section being uni-run. The calender stack is a 6 roll hard nip stack.

This paper reviews the history of the problem and the solutions to the problem.

Cockling

Cockling is a term used to describe a wavy pattern on the surface of paper. Typically, the paper will be smooth on the reel immediately after turn-up. After it sits for a few minutes, the surface of the paper has a wavy pattern in it. In this mill's case, the pattern was the typical diamond shape separated by regions of smooth paper.

Register in Forms

Forms refers to paper which is pulled through a printer using tractor holes along each edge of the sheet. This includes all the paper for the 9 pin and 25 pin impact printers that were used extensively in the past. It is also used in large quantity in banks and other large institutions. Forms are usually perforated for easy separation of the sheets, folded along the perforations and stacked in a box. Sometimes the forms have lines, usually green, printed on them. At other times they are left unprinted.

The converting operation converts rolls of paper to boxes of forms. Quality requirements for forms demand that the tractor holes line up in the stack through the complete box. They also demand that the perforations used to separate sheets are at the location where the printed lines on the sheet indicate they will be.

This mill had problems with both the tractor holes and perforations. An extensive effort to minimize the problem was initiated.

Wrinkling

The basis weight pulsations were also shown to have an effect on wrinkling in the calender stack. It was noted that, although the basis weight variations were not excessive, the results in terms of wrinkling and cockling on the reel were excessive. This indicates that another phenomenon, such as dried-in strains, was amplifying the effect.

Discussion

Cockling

Cockling is attributed to greater expansion of the paper in the cockled areas and less expansion in the smooth areas. The differential expansion can come from a non-uniform moisture content on the reel. Within a few minutes the outer wrap of the paper reaches moisture equilibrium. The regions that had a lower moisture content will have picked up more moisture causing a greater hygro-expansion of the sheet in these regions.

The second mechanism that causes cockling results from a non-uniform drying history. This non-uniform drying history leaves the paper with a non-uniform dried-in stretch. Upon rewetting, the amount that paper will expand is a function of drying restraint or dried-in stretch.

Register

There are three main reasons for register variations to occur in the converting operation, all relating to unequal stretch or strain of the web.

One source may be tension variations in the forms converter. These tension variations are the same for paper from all the suppliers coming into the pressroom. The only way they can affect paper from one supplier in a different manner from another supplier is through the modulus of elasticity of the sheet as shown in Figure 1. A higher modulus will result in lower strain variations caused by the pressroom tension variations. A sheet with more fibers oriented in the machine direction and made at a higher draw will have a higher modulus. Pulp type, refining, and the bonding of the fibers will also affect the modulus.

The second source can be explained by considering paper going through a perfect converter that imparts no tension variations. Modulus variations in the paper will then cause variations in stretch as shown in Figure 2. The only control a pressroom has over this variation is to lower the press tension to reduce the stretch variation. A paper manufacturer's only control is to ensure the paper has a uniform modulus. The main properties affecting the modulus uniformity are the specific modulus uniformity as measured by an ultrasonic stiffness measuring instrument, and basis weight variations. The specific modulus uniformity is affected by fiber orientation uniformity, sheet moisture variations, dried-in strain uniformity, draw variations, and calendering variations. Many of these variations are secondary and related to basis weight variations.

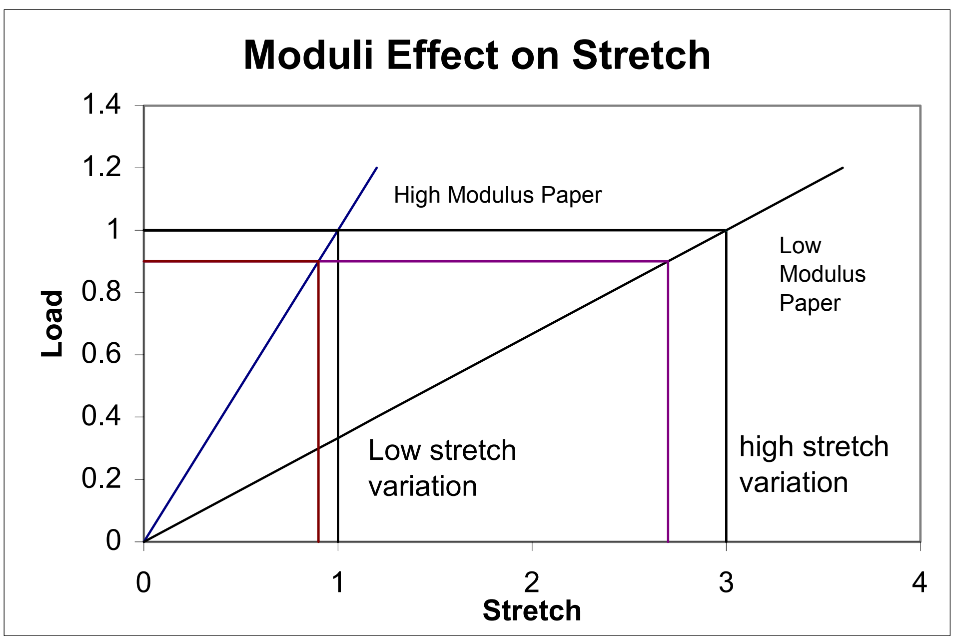


Figure 1 Stretch variation with load for two different moduli

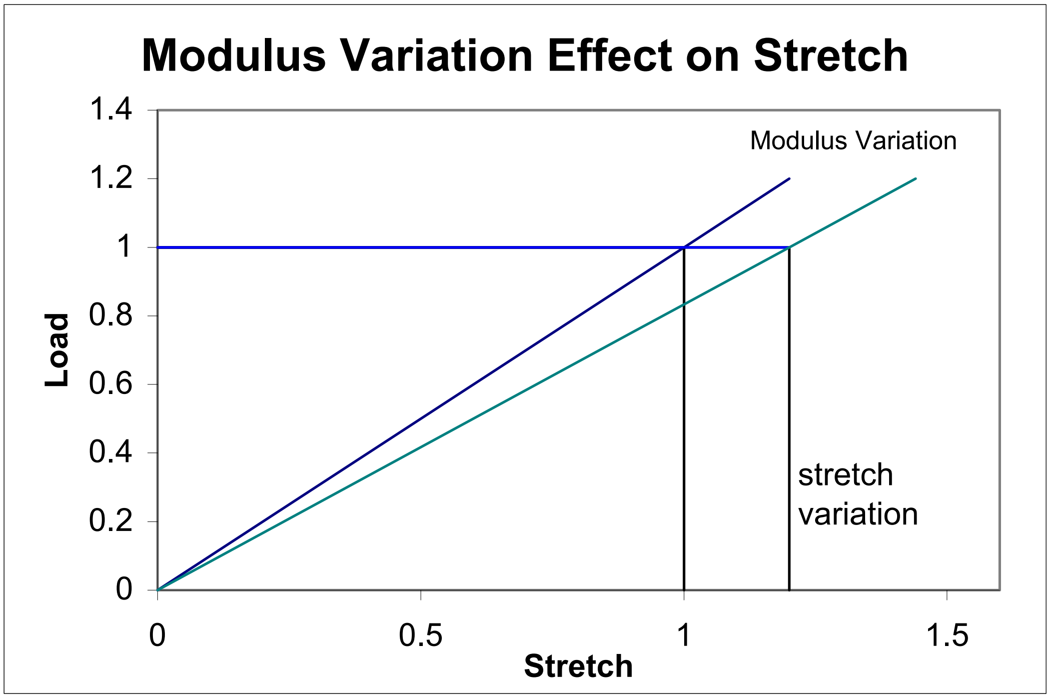
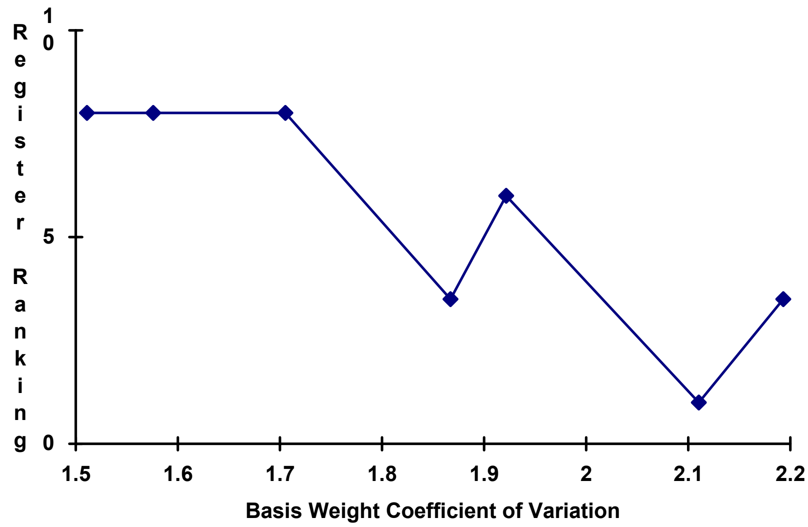


Figure 2 The effect of variations in Young's modulus in mis-register

The third method by which register variations can be introduced is through non-uniform dried-in strains resulting in non-uniform paper stretch when the paper is moisturized during the printing process. Non-uniform dried-in strains are caused by basis weight or moisture barring as discussed in the next section and will also result in a non-uniform modulus.

To confirm the above explanations of the causes of cockling and register variations, a trial was performed to compare the basis weight and its variability along with the modulus and its variability to the paper's register ranking, assigned by the converting press operators. This study showed the correlation with the basis weight variability as shown in Figure 3. Other properties measured, including sheet stiffness and tensile strength, showed no correlation with the register ranking. This trial confirmed the hypothesis that basis weight variations are critical in this problem. It certainly does nothing to support the hypothesis of modulus variations being an important factor.

This could be due to many fewer stiffness measurements made or the effect may have been due to dried-in strains that would have been relieved by the time the stiffness measurements were made. Since the measurements were taken on printed forms, the dried-in stresses would have been relieved. Thus it was not possible to measure their contribution by measuring the basis weight variations. Measuring the basis weight variations is an indirect measure of the dried-in strains.



• Figure 3 Register Ranking vs. basis weight variability

Drying History

A non-uniform drying history is caused by a non-uniform moisture profile entering the dryer section due to basis weight barring or press barring. First consider the lighter basis weight paper between regions of heavier basis weight. Because it has a lower basis weight, there is less water per square meter. This paper will dry to a given moisture content earlier in the dryer section than the heavier paper. Since it has the heavier basis weight paper around it, with a higher moisture content, the lower basis weight paper will have a lower than average restraint. This allows the low basis weight areas of paper to shrink more than the average amount.

Since the surrounding paper is of higher basis weight, this aspect will counteract to some extent the additional moisture of this region. It is expected to be a secondary effect. Press barring will give a similar, but slightly more pronounced problem. With press barring the bone dry basis weight is uniform; there is only a variation in the quantity of water going in the drier section. The final result is both a non-uniform modulus and non-uniform dried-in strains. Both of these can cause cockling and register problems in the paper.

Now let us follow through what happens when the paper is rewetted. First, let's make the (false) assumption that the paper has a uniform moisture content when it arrives on the reel. Let's also assume the moisture content is below the equilibrium moisture content for the relative humidity of the room. All the paper exposed to atmosphere will gain the same percentage of moisture. The low basis weight paper with the higher level of dried-in strain will elongate more than the neighbouring higher basis region. This will lead to cockling in the lower basis weight areas.

The lower basis weight areas do, however, have lower moisture content. This means that this paper will pick up a higher percentage of moisture from the environment, as compared to the high basis weight areas. This leads to a higher level of elongation as compared to the higher basis weight areas. This will add to the cockling in this area of paper.

The moisture variations can be caused by MD or CD basis weight variations, or by press barring. Since the smooth lines were bars across the width of the sheet, spaced about 100 to 150 mm apart, the problem was not a CD basis weight problem. While there were isolated incidents of press barring the major cause was related to MD basis weight variations.

A lower hygro-expansivity of the sheet will result in less growth of the paper for a given moisture uptake. This will reduce the amount of cockling in the paper.

Basis Weight Variations

To characterize the paper, a 22 mm (7/8 in) punch was used to collect paper samples from the smooth and the cockled areas. After conditioning the samples and weighing them, the basis weight of the smooth areas was found to be higher (up to 4%) with lower caliper. To be lower in caliper the high basis weight areas must have been wetter going through the calender stack. This confirms the hypothesis that the higher basis weight areas are wetter and dry later in the dryer section. It also confirms that the lower basis weight areas elongate more as hypothesized. Since this occurred without tension applied to the sheet, it is totally due to the dried-in strains.

Basis weight variations are usually caused by jet velocity variations due to pressure pulsations in the headbox or vibration of the headbox, but can also be caused by consistency variations or drainage variations.

The basis weight was measured off machine on a profilograph, which consists of a Beta gauge and caliper gauge. On machine production of 128 seconds of paper is fed slowly through the profilograph to get accurate measurements of the basis weight and caliper variations. This information is then processed to obtain a frequency spectrum of the basis weight and caliper variations. In many instances, there would be high basis weight frequencies present. Many of these could easily be related to a specific rotating component of the paper machine. Others were related to hydraulic turbulence in the stock approach system. When found, specific actions could be taken to reduce or eliminate the problem at its source.

During mill measurements, both an opacitel and the on-line Beta gauge were used to get a basis weight or related signal. The normal method was to measure the signal with a standard spectrum analyzer to determine the problem frequencies.

Amplification Effect

The basis weight variations are inconsistent, especially when viewed on a spectrum analyzer with the averaging off. This can also be seen by comparing the spectra with stable (rms) averaging compared to the peak hold average. This is attributed to the basis weight amplification on the wire effect best discussed by Moen[i]. The amplification effect is a function of:

Amplification=f(machine speed, distance to dry line, jet velocity variations,
frequency of velocity variations)

Less directly, the amplification would be affected by the drainage characteristics of the forming section up to the dry line (top former). Particularly harmful would be sheet sealing. The amplification effect is hard to predict in advance, but the results are easy to measure.

Of these the jet velocity variations must be brought under control for the best permanent reduction in variation. This will reduce the variations directly and affect the amplification effect, probably by reducing it. Reducing the distance to the dry line is also very effective. This can be seen by the reduction in basis weight variations when a top former is installed.

The only easy method to affect the amplification under normal operation is by changing the machine speed. If the basis weight variations are excessive, then the machine speed can be varied to attempt to reduce the variations. If the frequency of the variations is caused by a rotating component on the machine, then the frequency of the disturbance will also be varied by the machine speed change, having an additional impact.

Historical information has shown the basis weight coefficient of variation is a function of the machine speed, but there is a lot of variation not explained by the speed. Some of the variation can be explained by unmeasured variables such as the forming configuration, age and type of forming fabric, and drag. Some can also be explained by the amplification effect.

Other Paper Properties

Effects of Friction.

Forms use a friction drive to feed the sheet through the converting press. If this slips then it can have an effect on the register. Slippage has been reported as a problem by some converting operations. The tendency to slip is a function of the coefficient of friction of the paper among other things. Freesheet tends to have a very high coefficient of friction and runs well.

Some paper mills have experimented with friction enhancing components. Data shows that paper, which ran well, had a higher coefficient of friction, both in the paper mill when tested at the time of production, and when run by the converter.

Fiber Orientation.

Other studies were carried out to improve the dimensional stability for coated base stock. These showed that edge rolls are more prone to cockling than center rolls. This was related to the MD/CD sonic velocity ratios. Thus, any work to get these ratios more uniform throughout the width of the roll is advantageous.

Modulus.

As already mentioned, the stiffness of paper and its variability is important to paper performance. In one instance, paper that performed poorly had a 10% lower machine direction elastic modulus. In the same sample, the paper to paper static and dynamic coefficient of friction was much lower for the paper that suffered register loss.

Hygro-expansivity.

The hygro-expansivity of the sheet is related to the dried-in strains and pulp properties. Often green lines are printed on forms in the converting operation, adding water to the sheet. If the hygro-expansivity of the sheet can be reduced then the water addition will have a smaller effect. Improvements made to the machine included a change to divert fines to the other paper machine and converting the TCMP refining process to a TMP process. A study determined that with fines removed the hygro-expansivity coefficient of the pulp was reduced by 40%.

Drying Parameters.

Trials were also conducted to determine the effect of drying parameters. One study showed that lowering the pressure in the first dryer sections reduced the amount of cockling on the paper.

CORRECTIVE MEASURES

Fan Pump

The fan pump was replaced with a variable speed unit. The results do not show much difference from before and after the change except for one trial. Here the fixed speed drive with the control valve throttled did show a higher variability.

At another time, a piece of tank liner was caught in the fan pump impeller. This was found by taking pressure pulsation measurements with the pulsation frequency corresponding to the fan pump rotational speed. Removing the debris from the impeller rectified this.

Screens

One of the early problems identified was a screen vane pass frequency in the paper. To correct this problem the initial 2x2 rotors in the screens were replaced with a 12x2 rotor in the front screen and an 8x2 rotor in the back screen.

Secondary Screen Supply Pump

A high amplitude variation existed at the secondary screen supply pump vane pass frequency. The pump was conclusively determined to be the problem by turning the secondary screen and pump off. The problem was traced to an impeller designed for much higher consistency stock. When the impeller was replaced with a correctly sized unit, the problem disappeared.

Hydraulic Turbulence

Other basis weight variations were caused by cavitation in the recirculation valve. This problem was rectified by the installation of a low noise valve. A trial was performed to test different types of valves. A gate valve had the worst performance while a specifically designed low noise valve introduced the least cavitation. A butterfly valve gave intermediate performance.

Resonance of Headbox

A large portion of the problem consistently occurred in the 14 Hz range during the mid-eighties. Using modal analysis, the source for this frequency was traced to a resonant frequency of the headbox. Finite element analysis was used to design a new headbox base. The old base including the spacers were replaced with a new concrete base, which proved to be much stiffer and have more damping. This greatly decreased the level of basis weight variation.

Constrained Layer Damping

To further reduce the basis weight variation, constrained layer damping was added to the headbox and floor supporting columns. With this increased damping the level of headbox vibration was greatly reduced. It did not give a major improvement in the basis weight variation levels, which indicated that the vibration level of the headbox was no longer a major contributor to the basis weight variation.

Effect of Top Former

The level of basis weight variation was significantly reduced when the top former was installed. This can be explained by the dry line moving closer to the headbox. With a shorter distance from the headbox to the location where the sheet is formed there is less opportunity for a velocity variation in the jet to translate into a basis weight variation. This allowed the machine production to increase from 10.5 tonnes per hour to 12.5 tonnes per hour while maintaining basis weight uniformity targets.

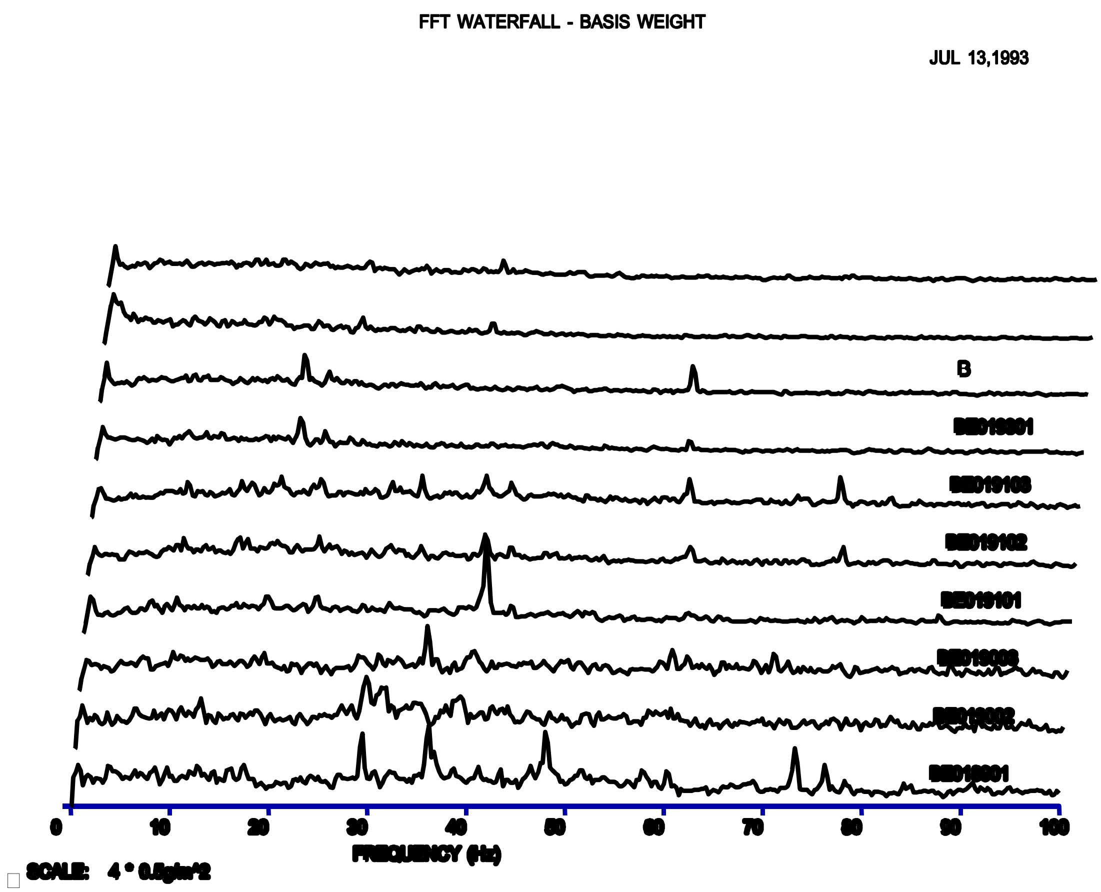


Figure 4 The basis weight spectra from a sister machine to the one considered here

Headbox Performance

The current headbox, an older generation bunched tube unit, was compared with newer hydraulic headboxes for possible further reductions in basis weight variability. In this comparison, the current bunched tube headbox performance equaled the newer hydraulic headboxes.

Pond Rotor

We desired to know the effect of the pond rotor in the headbox, also known as a rectifier roll or distributor roll. Trials were conducted that showed the roll rotational speed has a minor effect on the basis weight. The higher speeds (around 60 rpm) gave reduced variability in some trials, while another trial showed that a slightly lower speed was better. Conversations with personnel from the headbox manufacturer indicate that the rotational speed should be 8-12 rpm. This is much lower than some of the speeds that gave the lowest levels of variation in the trials conducted.

Another suggestion was that the rectifier roll should be moved as far as possible from the bunched tubes or remove this roll altogether. Based on this comment a study was conducted to determine the effect of the roll to tube spacing. In terms of the total variability, there was little effect. The spectra do show that different peaks are present with different spacing, but there were peaks in all cases. While roll removal has not been tried it remains as an alternative.

Effect of Drag

The basis weight variation was compared with drag level. A number of tests were performed giving contradictory results. In one instance, the lowest variability was at 2% drag and in another case at 4% drag. It must be noted that the real drag is a function of entrained air content on a given paper machine. The difference may be explained by such an error in the drag measurement or by another unmeasured variable.

On-line Basis Weight Measuring and Control Methodology

The amount of cockling in the paper is correlated to the basis weight variation. Other factors can affect the cockling of the sheet on the reel, such as the way in which the sheet is dried or moisture variations going into the dryer due to press barring. The basis weight variations have been found to be the most important and as such it was desired to measure and control for the critical forms grade.

The best reference for measuring the basis weight variations is an off-machine profilograph. This method is not practical for testing whether production in within specification, because it is a slow measurement, the results not known for hours after the sample was taken. A more practical solution was required.

The mill has implemented an online basis weight variability measuring system. The signal for this system comes from the on-line Beta gauge. The scanner is put in single point mode while the measurements are taken. The signal is fed into a spectrum analyzer which measures the peak in the spectrum in the 5-65 Hz range. The variability must be in an acceptable range for the paper to be suitable for the customer.

If the variability is excessive, the speed of the paper machine is reduced, as it is the easiest parameter to change to affect the basis weight amplification. The variability measurement is then repeated. The cycle repeats until the variability reaches an acceptable level.

Conclusion

Forms are usually made from free-sheet. This mill used TMP to make groundwood forms. As a new grade the performance requirements were not known. Through persistent effort, the single most important parameter was found to be the basis weight variability. The determination of instability was a challenging process. It required dedication and troubleshooting techniques as sophisticated as modal analysis. Then finite element analysis was used to ensure that one of the proposed solutions, a new concrete base for the headbox, would reduce the level of vibration by a sufficient amount.

With the implementation of an on-line basis weight measuring system, the mill had the tools and control required to ensure the variability was at an acceptable level before paper was shipped.

Acknowledgements

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References

[i] [i] C.J. Moen, **Basis Weight Barring, I. Amplification,** Vol. 60, No. 10, October 1977, Tappi